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Transport of trace gases in the subsurface of Mars

A. H. Stevens, M. R. Patel, S. R. Lewis, T. J. Ringrose, and M. R. Leese
 Department of Physical Sciences, The Open University, UK (adam.stevens@open.ac.uk)

Abstract

The ExoMars Trace Gas Orbiter (TGO) will have the capability of detecting and characterizing a broad suite of trace gases in the atmosphere of Mars. Interpreting the results of this mission will require an understanding of how these trace gases are transported from their sources, which may be deep underground, to the atmosphere. Here we present results of modeling designed to measure the timescales of release from putative subsurface methane sources. These transport timescales are far longer than mixing times in the atmosphere and could be up to 10 million years.

1. Introduction

Many of the proposed sources of the methane observed in Mars' atmosphere would occur deep in the crust. Candidates include the serpentinisation of mafic rocks [1] and colonies of methanogenic organisms [2]. Shallower sources include the decomposition of deposits of methane clathrate hydrate in the cryosphere [3]. The gas produced from all of these sources and other gases produced geologically in the crust will potentially have to travel through several kilometres of the martian regolith before they can be observed in the atmosphere by missions such as the TGO. We have produced a numerical model of this transport to quantify the timescales involved.

2. The model

We discretize Fick's second law, modified for a porous medium.

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z} \left(D(z) \frac{\partial C}{\partial z} \right) \quad (1)$$

where C is the concentration of gas, z is the depth in the subsurface and t is time.

The diffusivity, $D(z)$, incorporates the environmental variables that affect the diffusion of gas and is highly variable with depth.

$$D(z) = \frac{\phi(z)}{\tau(z)} D_{12} \left(\frac{T(z)}{T_{ref}} \right)^{\frac{3}{2}} \frac{P_{ref}}{P(z)} \quad (2)$$

where $\phi(z)$ is the porosity at depth, $\tau(z)$ is the tortuosity at depth, D_{12} is the free gas diffusivity of gas 1 in gas 2, T is temperature, and P is pressure. The reference temperature and pressure are those for the quoted value of D_{12} , which, for the diffusivity of methane in carbon dioxide, was taken from [4].

We currently know very little about the martian subsurface. The parameters above are derived from extrapolated martian surface measurements, results from terrestrial or lunar analogues and models such as [5].

Several parameters were varied to investigate their effect on diffusion. The transport rate is not sensitive to the subsurface temperature profile, but is very sensitive to the subsurface pressure profile, with D varying by several orders of magnitude between the two possible extremes of pore pressure values.

3. Results

Our simulations show that the timescale of transport from subsurface sources at realistic depths depends heavily on the source depth, concentration and production rate.

To measure the transport of methane we define a 'diffusion front' at the level equivalent to ~10 ppb in the atmosphere, approximating previously detected levels.

We also define a 'time to surface' by measuring how long it takes the defined diffusion front to move from the source to the surface.

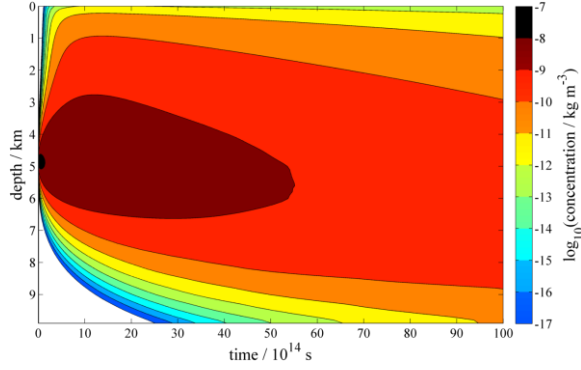


Figure 1: Contour plot showing the evolution of concentration in the subsurface for a source at 5 km depth. The diffusion front is shown by the yellow area. White areas are below a concentration of 10^{-17} kg m^{-3} .

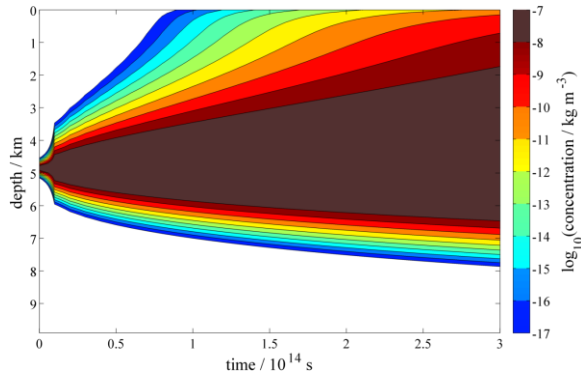


Figure 2: As Figure 1 but for a source with a continually producing source. Note the difference in timescale.

Depending on whether an atmospheric or lithostatic pressure profile is used in the model and whether a reasonable production rate is included, the timescales of release vary by several orders of magnitude from 10 to 10^7 years, as shown in Table 1.

Table 1: Estimates of how long methane takes to reach the surface for a range of given parameters

Pressure profile	Atmospheric		Lithostatic	
Source depth / km	2	5	2	5
No production	19 a	713 a	712 ka	-
Production rate $10^{-17} \text{ kg m}^{-3} \text{ s}^{-1}$	19 a	713 a	254 ka	9.6 Ma

6. Summary and Conclusions

The timescale of release from subsurface methane sources is potentially very long, up to several million years. This does not tie well with observations of methane in Mars' atmosphere that varies significantly over timescales of a year. Diffusion alone cannot explain variable release of methane into the martian atmosphere.

The parameters used in our model are poorly constrained. A deeper understanding of the martian subsurface is required to model trace gas transport more accurately. In particular, the pressure conditions in the subsurface are an important driver of gas transport and should be taken into account in further modeling. Future missions such as the InSight lander may help to constrain the subsurface environment.

Acknowledgements

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